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A preliminary study on use of cocoa pod husk as a renewable source of energy in Indonesia

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ABSTRACT

Indonesia is the third largest producer of cocoa bean in the world. One of the residues produced after removal of the cocoa bean from the fruit is cocoa pod husk (CPH). The objective of this work was to assess the use of CPH as a renewable energy source. CPH was sun-dried, crushed, and screened to obtain a particle size of less than 1 mm. Five grams mixture of CPH and binder in the proportion of 70% and 30% by weight respectively was pelletized and dried at 50 °C for 5 hours. Carbonization was performed at 400 °C for 2 hours. The results show that CPH has a high heating value of 17.0 MJ/kg. The air flow rate and fuel composition significantly affected the burning time and CO emission factor. The increase of carbonized CPH portion in the fuel increased the burning time of the pellet. The increase of air flow rate and carbonized CPH portion also increased the emission factor of CO.

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Introduction

Indonesia's economic development in the era of globalization led to an increase in energy consumption in all sectors of economic activity. It is estimated that the national energy demand will increase from 674 million BOE (Barrels of Oil Equivalent) in 2002 to 1680 million BOE in 2020, which represents a 2.5-fold increase or an annual average growth rate of 5.2% approximately (SMRTI, 2006). On the other hand, the national energy reserves will decrease if no new sources of energy are found. Therefore, policies need to be formulated to prevent an energy crisis. Also, the increase in energy demand is likely to result in increasing emissions to the environment. It is estimated that CO_2 emissions will increases from 183.1 million tons in 2002 to 584.9 million tons in 2020 representing a 3.2-fold increase (SMRTI, 2006). In order to prevent an energy crisis, the Indonesian government has issued the Blueprint of National Energy Management (2005–2025). The aim of this policy is to reduce energy elasticity to less than 1 as well as to realize an optimal energy mix so that the use of crude oil for power generation contributes less than 20% of the demand and new and renewable energy (NRE) contributes more than 5% of the demand by the year 2025. One of the missions of this plan is to manage energy ethically and sustainably, paying particular attention to environmental conservation.

One of the sources of renewable energy that has a great potential in Indonesia is biomass. Biomass has been used as an energy source since long and it has been one of the oldest significant energy sources, especially in rural areas. It is estimated that approximately 35% of the total national energy consumption comes from biomass including traditional use of biomass in the informal economy (DEMRI, 2003). The energy generated has been used for various purposes such as for household needs (cooking and household industry), drying of agricultural products, wood, ceramic, brick and tiles, as well as electric power generation in the sugar industry. Some biomass wastes such as wood waste, rice husks, bagasse, oil palm shell and municipal solid waste have a great potential for increased usage. The Indonesian government through the State Ministry of Research and Technology launched the roadmap of energy development including the production of solid and gaseous fuels from biomass for short, medium and long terms. In the short term (2005–2010), the governments plan was to support the biomass characterization program including briquetting technology focused on reducing environmental impacts and improving its efficiency (SMRTI, 2006). Utilization of biomass to replace fossil fuels for heat and electricity generation can reduce the problem of global CO_2 emissions (Moran et al., 2004) since CO_2 emitted by biomass combustion makes no net contribution, as it is absorbed by plants, provided the biomass is grown renewably (e.g. without deforestation). Biomass also has a lower sulfur content than coal, so that the emission of SO_X can be minimized.

One of the potential biomass sources which has been unused is cocoa pod husk (CPH). CPH is the residue produced after removal of

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the cocoa bean from the fruit (Fig. 1). Indonesia is the third largest producer of cocoa bean in the world, so there is abundant CPH in the country that is still being wasted. In 2008, the land area of cacao plantations reached 1,473,259 hectares, which means that there is an increase compared with the plantation area in 1995 which was only 428,614 hectares. Its production correspondingly increased from 231,992 tons in 1995 to 792,791 tons in 2008 (DAI, 2009). Adzimah and Asiam (2010) reported that the percentage weight of dry CPH and cocoa bean are 14.71% and 10.93%, respectively. It means that the potential of dry CPH is around 1.067 million tons in 2008. Currently, most of CPH is disposed at the plantation area so that after decomposition process it becomes fertilizer for cacao tree; a few farmers utilize it as animal feed. The utilization of the cocoa by-products, cocoa sweating and CPH, has been investigated by Agyeman and Oldham (1986). However, this work only studied the chemical composition of CPH after ashing to produce potash used either as a fertilizer or for liquid soap production. This waste (CPH) has good prospects for use as a biomass fuel in the future, so this needs to be studied. The objective of this work was to study the use of CPH as a renewable energy source by means of pelletisation and carbonization into high quality solid fuels and to investigate the combustion behavior of CPH in a chamber (Fig. 2).

Materials and methods

The material used in this work was CPH. Research was carried out by drying CPH under sunlight for 3 days. CPH then was crushed and screened to obtain a particle size of less than 1 mm. Five grams mixture of CPH and binder in the proportion of 70% and 30% by weight respectively was pelletized by using a 16 mm diameter-mold pelletizing machine and then dried in an oven at 50 °C for 5 hours. Carbonization of CPH was performed at 400 °C for 2 hours using an electrically heated reactor. Proximate analyzer and bomb calorimeter were used to determine the composition and calorific value of CPH.

Combustion tests were carried out in order to investigate the influence of air flow rate (experiment 1) and fuel composition (experiment 2) on the fuel combustion characteristics. The first experiment was conducted at constant wall temperature of 350 °C and air velocity ranging between 0.1 and 0.4 m/s, while the second experiment was performed at constant wall temperature of 400 °C and air flow rate of 0.3 m/s. LPG was used as a heating source for supplying heat to the reactor. A schematic diagram of the arrangement to undertake this work is shown in Fig. 3.

After the desired wall temperature was reached, the pellet was inserted into the reactor and placed on the cup which was hung by a wire connected to a digital balance. Measurement of mass and CO emissions was stopped, if the mass of pellet displayed a constant value indicating that the combustion was completed.

Fig. 1. CPH from cacao tree.

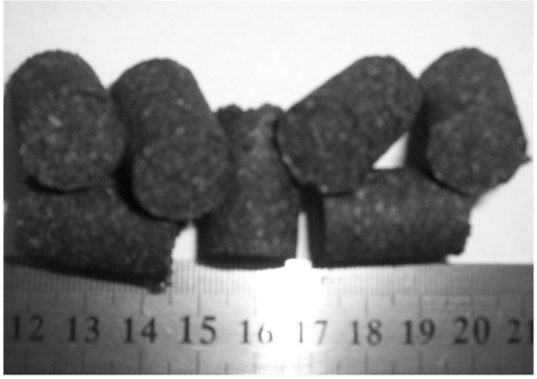

Fig. 2. CPH pellets using starch as a binder.

Results and discussions

Composition of CPH

A typical proximate analysis of raw and carbonized CPH is given in Table 1. As reported by others the higher heating value (HHV) of CPH has a similar value with other biomass such as rice husk (Madhiyanon et al., 2010), rice straw (Deng et al., 2009), bagasse (Filippis et al., 2004), jatropha curcas cake seed (Pambudi et al., 2010) and palm empty fruit bunch (EFB) (Konsomboon et al., 2011). The ash content of CPH is relatively high as compared with other biomass, such as bagasse (Filippis et al., 2004), EFB (Konsomboon et al., 2011), but it is lower than that of rice husk (Mansaray et al., 1999).

The high ash content of a biomass fuel inhibits the combustion process since oxygen cannot easily penetrate the ash to reach the burning biomass. HHV decreases with the increase of ash content in biomass materials, and therefore the good correlation between the HHV and the biomass ash content may be applied for estimating the HHV (Sheng and Azevedo, 2005). The HHV of biomass can also be calculated as functions of fixed carbon (FC) and volatile matter (VM) (Demirbas, 1997). However, ash also serves as a temporary storage of heat released, so that heat can be temporary stored in the combustion chamber.

The quality of CPH as a fuel source is substantially affected by its moisture content. An increase in the moisture content of CPH will decrease its HHV, which in turn reduces the conversion efficiency because a large amount of energy would be used for vaporizing the fuel moisture. Therefore, dry biomass is preferred for pyrolysis (Suarez and Beaton, 2003).

The high moisture and ash contents in biomass fuels can also cause ignition and combustion problems as also flame stability problems. Blending biomass with higher quality coal will reduce flame stability problems (Demirbas, 2004). However, biomass offers important

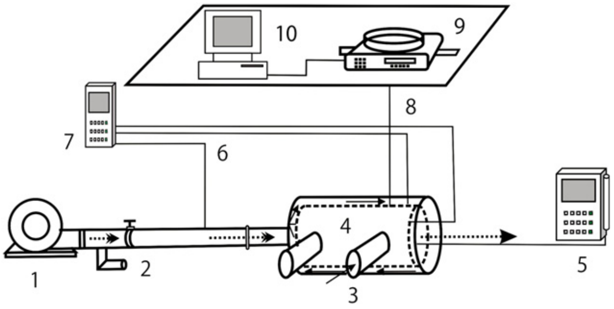

Fig. 3. A schematic diagram of combustion test : 1. air fan; 2. control valve; 3. LPG heater; 4. combustion chamber; 5. gas analyzer; 6. thermocouple wire; 7. digital thermocouple reader; 8. wire hanger; 9. digital balance; 10. computer.

Table 1
Proximate analysis of raw and carbonized CPH (wt.%).

	Samples	
	CPH	Carbonized CPH
Moisture	16.1	14.3
Volatile matter	49.9	11.4
Fixed carbon	20.5	50.6
Ash	13.5	23.7
HHV (MJ/kg)	17.0	21.7

advantages as a feedstock due to the high volatility of the fuel and high reactivity of both the fuel and the resulting char.

Effect of air flow rate

The effect of air flow rate on the mass loss of CPH is shown in Fig. 4. In general, the combustion of biomass is divided into three stages. The first stage is the drying or heating indicated by the slow reduction of mass. The second stage is the devolatilization reaction indicated by fast mass reduction and the third stage is burning of char with a slow mass reduction.

It can be seen that the increase of air flow rate increased the drying time since the gas temperature decreased as reported in previous work with other biomass (Pambudi et al., 2010). The higher the temperature of the gas, the faster the drying process. The shortest burning time occurred at an air flow rate of 0.2 m/s as shown in Fig. 5. Burning time was mainly affected by oxygen supplied to the pellet. A lower air flow rate results in less oxygen being supplied for combustion while a higher air flow rate lowers the gas temperature and reduces the residence time of oxygen in the chamber, resulting in insufficient time for oxygen to react with the carbon in the pellet.

Fig. 5 also shows the effect of air flow rate on CO emission. The CO emission of CPH is indicated by the emission factor which means the ratio of the weight of the CO released and initial weight of the biomass. It can be seen that the air flow rate strongly affected CO released; the increase of air flow rate increased the emission factor as with the increased airflow the biomass did not have sufficient time to react with oxygen to form CO_2. The highest emission factor occurred at the air flow rate of 0.4 m/s.

Effect of fuel composition

Fig. 6 shows the effect of fuel composition of CPH. Carbonized CPH ranging from 25% to 100% was added to the pellet. The results show that the higher the content of the carbonized CPH the slower the mass loss of the pellet. It can be inferred that carbonized CPH has higher quantity of fixed carbon than CPH since the carbonization process releases volatile matter in CPH, so that its content dramatically decreases, as can be seen in Table 1. The combustion of fixed carbon is slower than the devolatilization process in volatile matter as indicated in Fig. 7 where the increase of carbonized CPH portion in the fuel increased the burning time or decreased the combustion rate of pellet. The results also show that the residual mass of the pellet has different value since the ash contents of CPH and carbonized CPH differ, as can be seen in Table 1. The increase of carbonized CPH portion increased unburned biomass due to high ash content in carbonized CPH

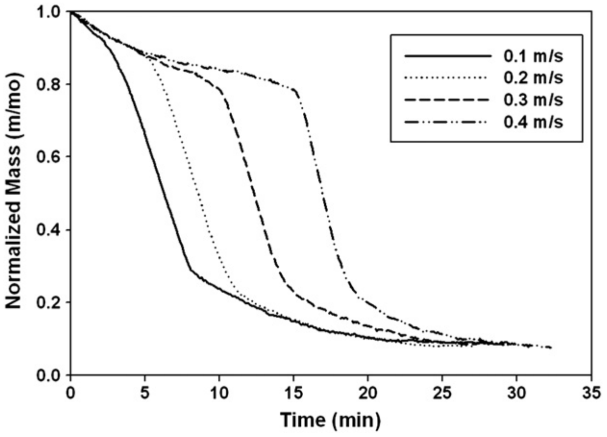

Fig. 4. Normalized mass versus time with different air flow rate.

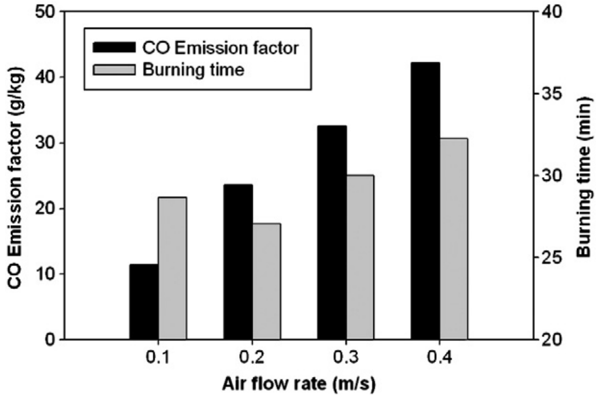

Fig. 5. CO emission factor and burning time of pellets under different air flow rate.

The CO emission from combustion of pellets with different fuel composition is shown in Fig. 7. It can be seen that an increase of the carbonized CPH portion increases the emission factor of CO. This is consistent with the theory that the higher content of fixed carbon needs more oxygen for completing the combustion process. For a constant air flow rate, it means that there is a lesser volume of oxygen available than the volume required for the higher portion of carbonized CPH, and therefore the CO released from the pellet cannot completely react to form CO_2. Stoichiometric analysis can be used to predict oxygen demand for the complete combustion.

Conclusions

Utilization of CPH as a renewable source of energy has been experimentally investigated. The result shows that CPH has higher heating value of 17 MJ/kg and relatively high ash content as compared with bagasse and EFB. The air flow rate and fuel composition significantly affect the burning time and CO emission factor. The shortest burning time occurs at an air flow rate of 0.2 m/s. The increase of carbonized CPH portion in the fuel increases the burning time of the pellet as carbonized

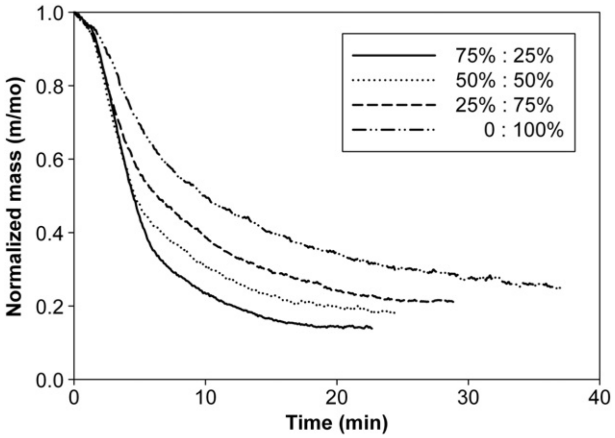

Fig. 6. Normalized mass versus time with different composition of fuel (CPH carbonized CPH - %wt).

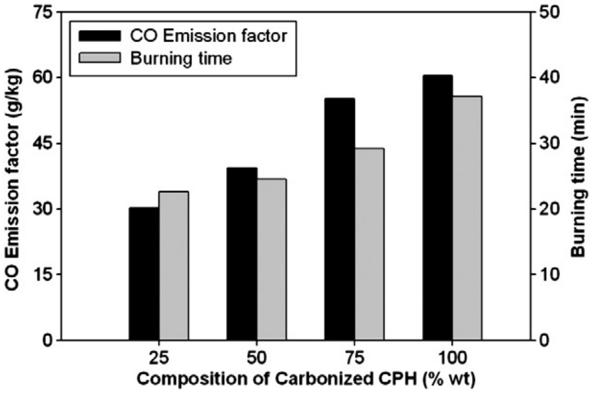

Fig. 7. CO emission factor and burning time of pellets under different composition of carbonized CPH.

CPH has higher fixed carbon content. Increase of air flow rate and carbonized CPH portion also increases the emission factor of CO due to higher fixed carbon content requiring more oxygen for completing the combustion process. A lower level of oxygen causes CO formation since the fixed carbon cannot completely react to form CO_2.

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